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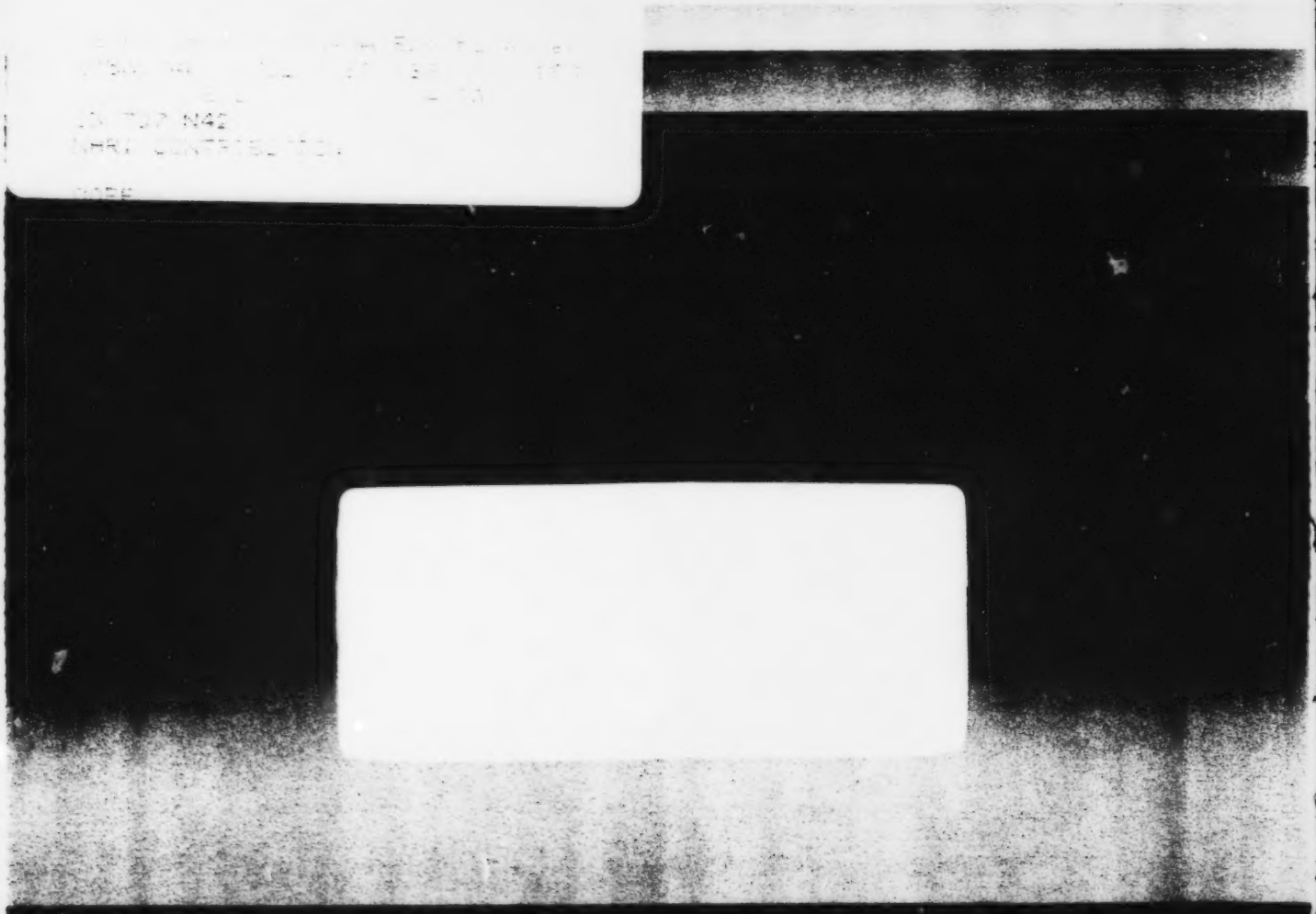

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WATER IN THE SOLID PHASE: THE STATE OF OUR SNOW AND ICE RESOURCES

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ABSTRACT

Snow and ice are major factors in the Canadian environment. They impact substantially on all phases of the economy, yet the information to summarise the present state of this environment is not available. This report indicates the general nature of water in the solid phase in Canada as it is found in glaciers, lake and river ice, snow and permafrost. The glacier and permafrost resource is being depleted. Snow and lake and river ice is responding to the increased variability of the climate. Possible impacts on the environment and economy of the future are considered should these trends continue.

RÉSUMÉ

WATER IN THE SOLID PHASE: THE STATE OF OUR SNOW AND ICE RESOURCES

by

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INTRODUCTION

Snow and ice are major factors in the Canadian environment and impact substantially on all phases of the economy. Despite this, the available data are quite sparse and unconsolidated. It is not possible to drav a clear picture of the present state of these resources.

The solid phase of our water resource includes the following:

a) Glaciers, which cover large areas of western and northern Canada and amount to some 20% of the area of the country covered in H_2O.
b) Lake and river ice, the form adopted over the remaining 80% during the winter.
c) Snow, which blankets most of the country for almost half the year, and
d) Permafrost and ground ice, the state in which much of the ground water in almost half the country is found.

Although individual human activities may affect snov and ice to some degree, collectively and individually they are most susceptible to temperature. Thus any global varming is likely to have more impact on this phase of our water resource than on the liquid phase. Symptoms such as the recession of glaciers, the disappearance of permafrost, depleted mountain and prairie snov packs have all been experienced in the 1980s. Some general comments can be made and inferences dravn as to the state of these resources.

GLACIERS

One major water resource that has been depleted during the 1980s is that contained in perennial snov and ice. The amount of fresh vater stored in this form in Canada is surprising, as it greatly exceeds the amount stored in the liquid phase in all our lakes and rivers.

The freshwater cover of Canada in lakes and rivers is 755 165 km². To this should be added the 195 059 km² of frozen surface water stored in perennial snow and ice. The total is almost 10% of our land area. The ice is very significant in the context of the static water balance. The liquid water amounts to some 20 000 km³, but the volume of water contained in the ice is estimated to be approximately 35 000 km³, excluding permafrost and ground ice. Unfortunately, accurate measurements of the ice-covered areas of Canada and their volume have never been made. The best estimates are given in Table 1 (after Ommanney, 1971).

Table 1. Estimated Glacierised Area

Region	Area km²	Number of gl.	Region	Area km²	Number of gl.
ARCTIC ISLANDS			**MAINLAND**		
Ellesmere	80,000	6,773	Pacific drainage	37,659	15,539
- ice shelves	500		Nelson River	328	1,524
Axel Heiberg	11,735	1,121	Great Slave/Arctic	1,466	1,692
Devon	16,200	1,920	Yukon River	10,564	3,368
Coburg	225	91	Labrador	24	
Meighen	85				
Melville	160				
North Kent	152	68			
Baffin	37,000	10,217			
Bylot	5,000	575			
Sub Total		20,765	**Sub Total**		22,123
Total Arctic	151,057	unknown	**Total Mainland**	50,041	unknown

The number of glaciers in Canada was estimated in 1975 at about 100,000. Table 1 includes a figure for the number of glaciers identified within the major hydrological/glaciological areas. Unfortunately, two things must be stressed. Firstly, the area of ice may well be underestimated by as much as 20%. Secondly, the numbers of glaciers are only those counted to date and may not reflect the actual number of glaciers in those basins!

With no comprehensive inventory of Canada's glaciers available, we are unable to state confidently how many there are, what area they cover, which of them is the largest, the longest, the deepest, etc. However, some approximate area figures for the better known glaciers and ice caps are given in Table 2 (after Young and Ommanney, 1984).

Table 2. AREA OF SELECTED CANADIAN GLACIERS AND ICE CAPS (km^2)

Arctic Islands		
Agassiz Ice Cap	17326	km^2
d'Iberville Glacier	1609	km^2
Ward Hunt Ice Shelf	660	km^2
Müller Ice Cap	6300	km^2
Iceberg Glacier	776.8	km^2
White Glacier	39	km^2
Devon Ice Cap	12825	km^2
Barnes Ice Cap	6200	km^2
Penny Ice Cap	6000	km^2
Yukon Territory		
Kaskawulsh Glacier	700	km^2
Klutlan Glacier	1091	km^2
Steele Glacier	99	km^2
Labrador		
Superguksoak Glacier	1.8	km^2
British Columbia		
Bridge Glacier	83.5	km^2
Franklin Glacier	132	km^2
Grand Pacific Glacier	565	km^2
Illecillewaet Glacier	6.4	km^2
Place Glacier	3.8	km^2
Sentinel Glacier	1.8	km^2
Alberta		
Athabasca Glacier	15	km^2
Columbia Icefield	325	km^2
Peyto Glacier	13	km^2
Ram River Glacier	1.8	km^2
Saskatchewan Glacier	30	km^2
Victoria Glacier	3.5	km^2

Much of the ice is quite old, although its age varies considerably. Ice cores taken from the bottom of the Agassiz Ice Cap on Ellesmere Island, by scientists working with the Geological Survey of Canada, pre-date the last major ice age. Basal ice there is about 130 000 years old! The Barnes Ice Cap on Baffin Island is a remnant of the Wisconsinan Ice Age. It nourishes itself and no ice cap could exist in that location if one was not there already. A slight warming could raise the freezing level above the top of the ice cap and make it unable to sustain itself. An Environment Canada project has obtained 300-year old ice from the top of Mount Logan and it is expected that ice up-to 1000-years old can be retrieved from that site. In the Rockies the ice is younger. The residence time of ice in the Columbia Icefield, i.e. the time it takes for a snowflake that falls near the centre of the icefield to turn to ice and flow out through the snout of the Athabasca Glacier, is in the order of 200 years. Ice in the smaller glaciers should be correspondingly younger. However, the time that glaciers have occupied a particular location is another matter. Wood discovered in and around the moraines of glaciers in the Rockies and appearing from under the ice has been variously dated at anywhere from 3000 to 8000 years B.P.

Visitors to the Rockies, or other glacierised areas of Canada, will have seen the extent of the contemporary depletion of the glacier resource with their own eyes. The shrunken tongues of ice lying between towering lateral

moraines are telling evidence of the extent of glacier recession in Canada since the Little Ice Age, which ended in the latter part of the 1800s. The glacier monitoring programme in Alberta and British Columbia was cancelled in 1980. Today there is no systematic monitoring of this resource and no way to tell the extent or rate of its depletion.

In the event of a significant global warming, much of this ice will melt. Although in the short term the melt water will augment stream flows and be of temporary benefit for agriculture and hydro generation, etc., in the long term it will contribute to rising sea level and cause serious problems for any low-lying coastal settlements. Glaciers in the Front Ranges of Alberta could disappear entirely. The ice cores of moraines damming pro-glacial lakes could melt, leading to serious floods when the dam is breached. In the north, moderating ice temperatures might lead to changes in ice-flow regimes and the triggering of glacier surges. Lakes created by ice-blocked valleys release suddenly causing catastrophic floods (jökulhlaups), orders of magnitude greater than precipitation- or snowmelt-induced floods. In the Arctic, increased glacier activity could result in greater iceberg production threatening shipping lanes and offshore activity. Finally, increased glacier-melt may cause severe erosion and elevate sediment loadings in glacier-fed streams and degrade fish spawning grounds and water quality. Mining of glacier ice, such as that on Mount Cline, is expected to have minimal impact in comparison to climate change.

LAKE AND RIVER ICE

Lake and river ice affect Canadians in a number of different ways. While the first skim of ice conjures up visions of skating for city dwellers, for the northerners it is the harbinger of ice roads and cheaper freight rates for southern goods. The duration and thickness of the ice cover is an important factor in the northern economy. A current analysis of freeze-up and break-up dates is not available. However, one that extended an earlier data base to 1984 showed the dates differed little from those shown in the Hydrological Atlas of Canada (Plate 19) using data to 1977. Freeze-up also represents a period of increased mobility for many Canadians as frozen rivers and lakes permit easier cross-country travel. Conversely, break-up is a time when vehicles cannot use ice roads and boats cannot use the rivers. Ice jams in the river often causing serious flooding. Whether the break-up of the ice and

jam is a thermal or mechanical event can influence the severity of the problem.

In the south, the length of the operating season on the St. Lawrence Seaway is controlled by ice. Ice jams in certain sections, such as that through Lake St. Clair can inhibit ship passage and be very costly. A 20-day jam in 1984 cost shippers an estimated $23 million. Municipalities may resort to cutting and blasting to relieve ice conditions that threaten urban structures.

Finally, the thickness and transparency of the ice cover affects aquatic life in ponds, lakes and rivers. Any change in the climate will affect this part of the water cycle and could mean the difference between survival or extinction for the species concerned.

SNOW

Variations in the snow resource have a significant impact on the availability of water during the warmer months. Depleted snow packs in the mountains, such as have been experienced during the 1980s, led to substantially reduced stream flows and concern over water availability (PFRA). In the prairies, the lack of adequate winter snow exacerbated the drought because spring snow melt failed to fill potholes and dugouts or provide adequate soil moisture for seed germination.

Snowfall and the depth and length of snow cover are intimately linked to variations in the climate. We cannot say that the resource as such has been depleted, but that the stationarity of the statistical record is now in doubt. In some areas amounts have been significantly below normal and in others considerably above. This has serious implications for managing those parts of our economy that are affected by snow, such as:

a) Recreation - Federal publications have already reported on the possible economic consequences for Ontario of the loss of its downhill ski industry and the curtailment of that in Quebec. Reduced snow packs would also influence cross-country skiers and snowmobilers with the consequent reduced activity in the industrial and retail infrastructure that supports them. The impact on water supply of this reduced snow cover has not been considered. However, global warming might lead to higher snowfalls in the Cordillera, because of the higher moisture content of the air masses, and brign with it an expansion of recreational activity.

b) Municipalities - Significant proportions of many municipal budgets are devoted to snow clearance. Snow dumping activities contribute to land and water pollution because of salts and "leaded" sand in the snow. In addition, there is the roadside vegetation kill and rust damage to vehicles from chemicals used to keep the roads usable. Depending on whether the depth and duration of the snow cover increases or decreases, taxpayers and the environment could be affected positively or negatively. Building codes might have to be modified to reflect changing snow load criteria.

c) Transportation - A major economic cost of maintaining roads, railways and airports is that related to dealing with snow and ice. A shorter snow season would reduce expenditures in this area. Higher snowfall in the west could lead to greater road and railway maintenance costs there and to an increased danger from avalanches. However, water supplies would likely increase.

d) Agriculture - Low snow years are the bane of western farmers because the soil moisture cannot be replenished properly. If this is a realistic scenario for the future, then snow trapping techniques will have to be adopted and more invested in an infrastructure to deliver water to users. This could well involve the inter-basin transfer of water.

Although ice nucleates spontaneously at -40°C, snow usually forms at a higher temperature and uses available aerosols as nucleating agents. Through this process, and by falling through the atmosphere, snow is able to scavenge many of the atmospheric pollutants. These lie in the snow cover and are concentrated until spring melt when they are released into the aquatic environment creating what has been called an "acid shock". During the 1980s there has been evidence for the increase of acid rain and acid snow, both of which have degraded the aquatic environment. Unless emissions from vehicles and industry are reduced, we can expect further such destruction in the future.

A final aspect relates to the thickness of the snow cover itself. For both fauna and flora the depth and nature of the snow cover dictates whether they can survive the winter or not. Changes in snow cover might be too rapid to allow for adaptation or migration.

PERMAFROST

As the distribution of permafrost in Canada is related to air temperature, any

warming of the climate will likely lead to the northward migration of the southern limit of continuous permafrost and the disappearance of some of the existing areas of discontinuous permafrost. Evidence for this has been found by scientists from the National Hydrology Research Institute in a study along the Mackenzie Highway from Keg River to Hay River, N.W.T. where the permafrost limit appears to have moved northward by as much as 120 km in the last 25 years. Loss of permafrost will lead to changes in the hydrological regime, i.e. increased infiltration and liquid water content, run-off, erosion, etc. and may have serious consequences for northern roads, highways and buildings that have been designed for a thermal regime which may not longer exist.

CONCLUSION

Although the information to summarise adequately the present state of the snow and ice environment in Canada is not available, some trends have been identified. Glacier water has been lost from storage in the mountains, "permafrost" water in some parts of the north has changing to the liquid state, and snow and ice generally, being in phase with the climate, are becoming increasingly variable. Statistical models, which assume a stationary time series, are becoming less appropriate and can no longer be used with assurance. In order to have sustainable development, future strategies will require much better knowledge of hydrological processes. Unfortunately, Canada has few people working in this area and even fewer being trained to follow in their footsteps. This may limit our ability to respond to the changes taking place in this environment.

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